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Class II Composite Restorations: Importance of Cervical Enamel *In Vitro*

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Clinical Relevance

The presence of enamel at the cervical margin of a class II preparation increases the fracture strength of the composite restoration at the marginal ridge, but fractures are more complicated when they occur.

SUMMARY

Objective: This study evaluated the importance of enamel at the cervical margin for support and retention of a class II composite restoration in relation to fracture strength, fracture mode, and leakage. Methods: Sixty-five newly extracted teeth were randomly divided into five groups. Within each group, standardized class II preparations were made at the mesial surface of the tooth with four different preparation designs. Group D (n=15) had the cervical margin placed below the cemento-enamel junction (the dentin group), and in the other three groups (the enamel groups: E1, E2, and E3), the cervical margin was within the enamel (n=15 each). Group E3 had restorations with cuspal coverage, while groups E1 and E2 differed in vertical dimension. Intact teeth without preparation or restoration were tested as controls (n=5). The area of the horizontal part of enamel at the cervical margin of the preparation (available cervical enamel) was calculated. The teeth were restored with a nanofilled composite material and an etch-and-rinse adhesive system. The teeth were subjected to artificial aging consisting of thermocycling and mechanical cyclical loading. The restorations were subsequently loaded until fracture. The teeth were examined microscopically to assess fracture mode and leakage at the interface between the restoration and the tooth substance. Results: The fracture strength in group D (without cervical enamel) and E3 (with cuspal coverage and cervical enamel) was lower ($p<0.01$) than in the other two groups (with cervical enamel). There was a correlation between the area of available cervical

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enamel and fracture strength (p<0.01). The median fracture strength for the control teeth was not significantly different from groups E1 and E2. Group D exhibited a predominance of adhesive fractures, while the other groups revealed more cohesive fractures. Conclusion: The results from this study indicate that available cervical enamel has an impact on the performance of class II composite restorations.

INTRODUCTION

The use of direct composite restorations in dentistry has increased during recent decades.[1-8] While the scientific consensus in the 1990s supported the use of composite restorations only in small class I and class II cavities with little or no occlusal function and with cervical margins within enamel,[9] today this use has expanded to a wide range of applications.[10,11] Developments in the properties of composite materials[12,13] and associated adhesives,[14,15] increased esthetic demands,[16] and concerns about the adverse effects of dental amalgam[17] are factors contributing to this change.

Today, extensive posterior preparations may be restored with resin-based composite instead of amalgam or indirect restorations, as reflected in the directions for use of the products from the manufacturers. However, the use of composite in extensive posterior preparations is associated with some clinical challenges. For instance, extensive posterior restorations are often extended to or below the cemento-enamel junction (CEJ), leaving little or no enamel at the cervical margin. Studies have shown increased marginal leakage when the cervical margin is located below the CEJ.[18-21] Postoperative sensitivity is one of the reported clinical complications of leakage between the tooth substance and the restorative material.[22] In addition, some *in vitro* studies have indicated that there is a relationship between leakage and secondary caries, but this has not been confirmed in clinical studies.[23-25]

While the relationship between available cervical enamel and leakage has received much attention, there is little information concerning the influence of cervical enamel on the fracture strength of the marginal ridge of a composite class II restoration. Such fractures (Figure 1) are often observed in failed clinical restorations. Fractures, together with secondary caries, are considered to be among the primary reasons for composite failure.[26-28]

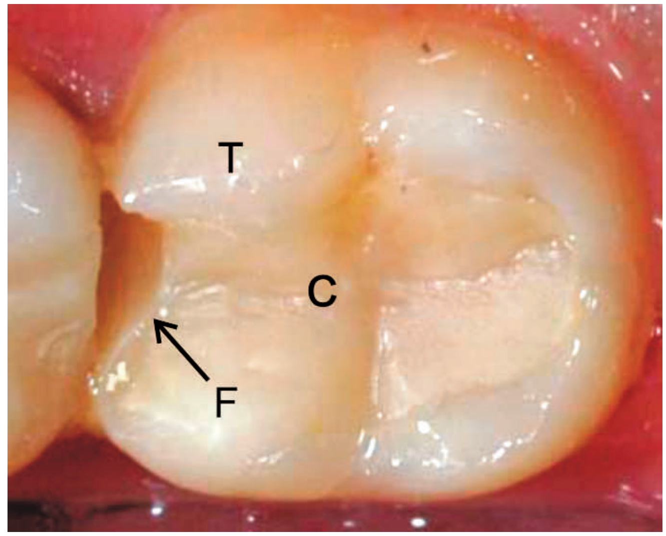

Figure 1. *Fracture of the marginal ridge of a composite class II restoration in a posterior molar in a clinical setting (C=composite, T = tooth substance, F = fracture).*

The aim of this *in vitro* study was to study the association between the area of available cervical enamel and fracture strength and fracture mode of the marginal ridge of a composite class II restoration and leakage at the interface between the restorative material and the tooth substance.

In this study, the term "available cervical enamel" is used to describe the horizontal part of enamel at the cervical margin of the preparation.

METHODS AND MATERIALS

Sixty-five newly extracted sound human third molars were selected. Immediately after extraction, the teeth were stored in phosphate-buffered saline containing 0.2% sodium azide in a refrigerator at +4°C and were kept moistened in the solution continuously before and after the restorative, aging, and test procedures. They were visually inspected in a light microscope, and teeth with visible defects or infractions were replaced by defect-free teeth.

Preparation Designs

The teeth were randomly divided into five groups (D, E1, E2, E3, and controls). Groups D to E3 comprised 15 teeth each, and the remaining five teeth were used as controls. Within each test group, a specific standardized class II preparation was made at the mesial part of the tooth, with four different preparation designs (Figure 2).

Group D had a cervical margin located below the CEJ (the dentin group); in the other three groups,

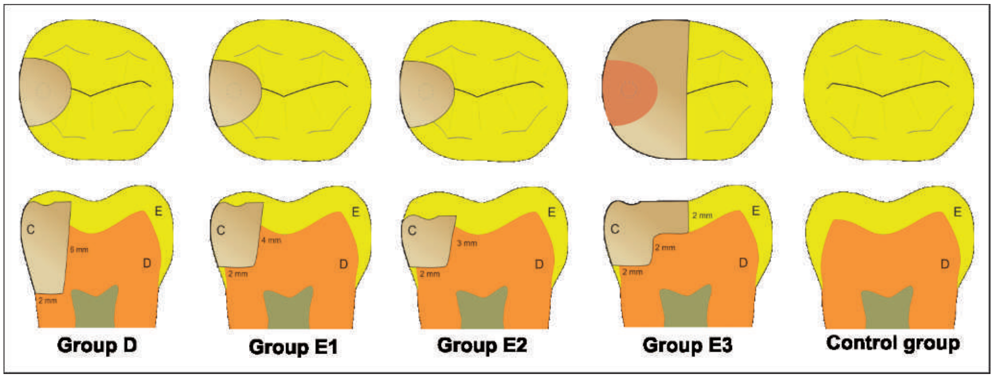

Figure 2. *Standardized preparation designs and composite restorations (C) with the cervical margin located below the CEJ (group D, the dentin group) and above the CEJ (groups E1, E2, and E3, the enamel groups). Groups E1 and E2 differ only in height (4 and 3 mm, respectively), and group E3 has a cuspal coverage. The control group comprised intact healthy teeth without any preparation or restoration.*

this was above the CEJ (the enamel groups). Group E3 had restorations with cuspal coverage, while groups E1 and E2 differed only in height of the restoration (4 and 3 mm, respectively). The reason for these two different heights was to evaluate the effect of the restoration height on the fracture strength. The teeth in group E2 were initially prepared as E1 (4 mm) and thereafter reduced from the occlusal portion to a height of 3 mm. The gingivo-proximal box in all preparations was standardized for each group, using a flat-ended conical diamond bur with a cervical diameter of 2 mm (CERANA® Class II; Nordiska Dental AB, Ängelholm, Sweden).[29] The dimensions of the prepared cavity were controlled with a periodontal pocket probe. All preparations were performed without any type of bevel.

Calculation of the Available Cervical Enamel Area

After preparation, the preparations were observed and imaged using a light microscope (Leica DM IRM; Wetzlar, Germany), and the area of available cervical enamel (Figure 3) was calculated, using imaging software (NiS-Element AR Software; Laboratory Imaging, Prague, Czech Republic). The area was imaged and measured two times and the average of the two values used as the final enamel area.

Restoration

The preparations in groups D to E3 were restored with a universal nanofilled composite material (Filtek Supreme XT; 3M ESPE, Seefeld, Germany) and an etch-and-rinse adhesive system (Adper Scotchbond 1 XT; 3M ESPE). An oblique incremental layering technique was performed with layers not thicker than 2 mm. An LED curing device (Elipar FreeLight 2 LED; 3M ESPE) was used, and each layer was cured for 40 seconds with an intensity of approximately 1000 mW/cm^2.

The occlusal surface of the restoration was designed to match the loading plunger by gently pressing the plunger into the last occlusal layer of composite before polymerization. The center of this

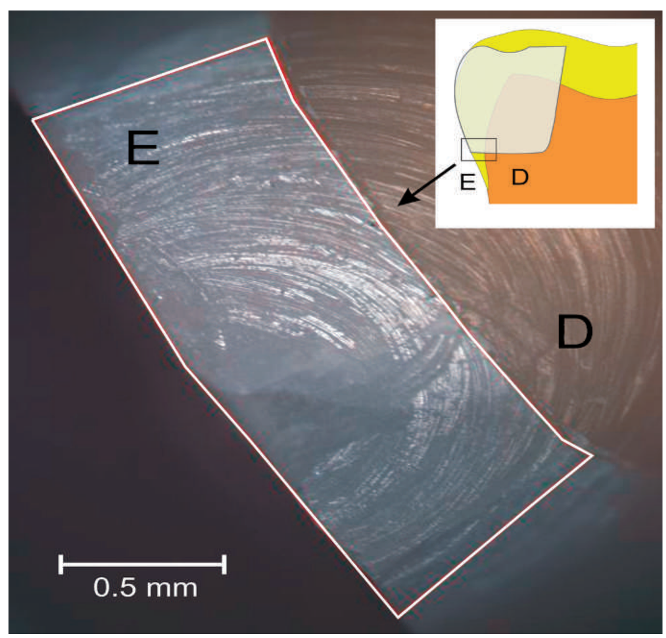

Figure 3. *Microscopic occlusal view (5×) of the available cervical enamel (E) and the adjacent dentin (D) in a preparation. The traced white lines indicate the outline of the available cervical area. The enamel area on both sides of the marked area is out of focus on the photograph, indicating that this part of the enamel is located in the buccal or lingual wall of the preparation.*

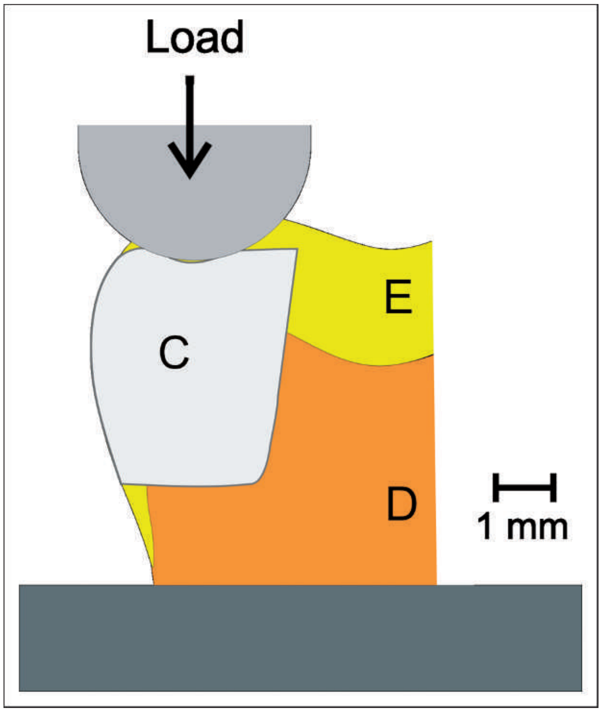

Figure 4. *Load application at the occlusal surface of the composite restoration (C), parallel in relation to the vertical axis of the tooth (E = enamel, D = dentin).*

precontoured groove was placed 1 mm from the center of the marginal ridge (Figure 4).

During the restoration procedure, the teeth were mounted in a base of gypsum together with one adjacent tooth, and a precontoured circumferential molar matrix system in stainless steel was used together with anatomical wedges (KerrHawe, Bioggio, Switzerland).

Artificial Aging

All teeth in groups D to E3 were subjected to 5000 thermal cycles in two water baths of 5°C and 55°C, with 20 seconds of soak time in each bath and a two-second transfer time. Thereafter, the teeth were preloaded with 10,000 cyclical loads between 30 and 300 N at 1 Hz at a temperature of 37°C. The direction of the preloading was parallel to the vertical axis of the tooth. The preloading process took place in a container with a water-based tracer material (Indian ink; Royal Talens, Apeldoorn, Holland).

Load to Fracture

Subsequent to artificial aging, all specimens in all five groups were loaded in a servo-hydraulic mechanical testing machine (MTS 810; MTS-systems Corp, Minneapolis, MN, USA) with a cross-head speed of 0.01 mm/s until fracture occurred. A stainless-steel plunger with a 4-mm-diameter ball end as load application was placed in the precontoured fossa on the occlusal surface of the restoration or the corresponding location on the unprepared teeth in the control group, parallel to the vertical axis of the tooth (Figure 4).

The loads at fracture and fracture mode were recorded. The fracture was classified as cohesive if it was located within the restorative material and as adhesive if the total amount of restorative material was separated from the tooth at their interface. If tooth substance at the cervical margin was pulled away during the fracture test, this was recorded as enamel tear-out.

The teeth were inspected in the light microscope to register any leakage at the cervical margin of the preparation. In cases where the cervical part of the restoration remained in the preparation cavity after fracture, the tooth-restoration complex was vertically sectioned through the middle part of the cervical margin. In those cases where parts of the cervical margin were pulled away with the restoration (tear-out), the photos taken after the artificial aging process were studied. If there was no visual staining at the cervical margin, it was classified as having no leakage. If staining was observed, it was classified as having leakage in enamel.

The five teeth in the control group were not restored or aged but were tested for fracture strength at the marginal ridge.

Statistical Analysis

All analyses were performed using a statistical software package (SPSS, version 15.0, SPSS Inc, Chicago, IL, USA). To compare the fracture strength in the four groups, the nonparametric Kruskal-Wallis test was used with a p-value of 0.05. To investigate the association between the area of available cervical enamel and the fracture strength, the nonparametric Spearman rank order correlation coefficient was calculated. Logistic regression was performed to analyze the influence of the area of available cervical enamel on the fracture strength of the cervical margin of the preparation.

RESULTS

The fracture load in groups D and E3 was significantly lower than in the other two groups (p=0.002), while there was no significant difference between groups E1 and E2 or between groups D and E3

Table 1: *Description of the Available Cervical Enamel and the Load at Fracture of the Restorations and Controls*

Group	N	Number of Fractures During Mechanical Cycling	Area (mm^2) of Available Cervical Enamel (Median, Mean)	Load at Fracture (Newton)		
				Median, Mean	Minimum, Maximum	Q1, Q3, SD
D	15	0	0	963, 951	593, 1189	787, 1123, 202
E1	15	0	0.9, 0.9	1451, 1410	452, 2183	1269, 1676, 419
E2	15	0	1.2, 1.2	1362, 1401	758, 2018	1276, 1626, 316
E3	15	5[a]	0.7, 0.7	1129, 1026	300, 2054	300, 1542, 627
Control	5	—[b]	—[b]	1414, 1411	1042, 1811	1145, 1675, 291

Abbreviations: Q1, first quartile; Q3, third quartile; SD, standard deviation.
[a] *Five restorations in group E3 fractured during the mechanical loading in the aging process.*
[b] *The teeth in the control group were intact and not subjected to aging.*

(Table 1). Five restorations in group E3 fractured during mechanical loading in the artificial aging process and could therefore not be tested for fracture load. The maximum load in the aging process was 300 N, and the fracture load of these five restorations was therefore established as 300 N. In the other groups, there were no fractures during the preloading process.

The load at fracture of the controls (control group) did not differ significantly from the fracture load in the enamel groups E1 and E2.

There was a significant correlation between the area of available cervical enamel and fracture load when all groups were pooled (Figure 5) (Spearman rank correlation coefficient: 0.51, $p<0.001$). If group D (without any enamel at the cervical margin) was excluded, the correlation coefficient was 0.32 ($p=0.035$). No significant correlations were observed within each of the three enamel groups (groups E1, E2, and E3).

The dentin group (group D) had a predominance of adhesive fractures, while the enamel group E1 had a predominance of cohesive fractures (Table 2). Groups E2 and E3 had nearly even distribution of adhesive and cohesive fractures. All restorations in group E3 had a remaining cuspal coverage part after fracture test (Figure 6), but when looking at the proximal box in isolation, about 50% of the restorations had adhesive fractures.

Fracture of tooth substance at the cervical margin of the preparation was seen significantly more frequently in the enamel groups (Table 2). Logistic regression indicated that when increasing the area of available cervical enamel, the probability of fracture of tooth substance increased (odds ratio=3.85, $p=0.023$).

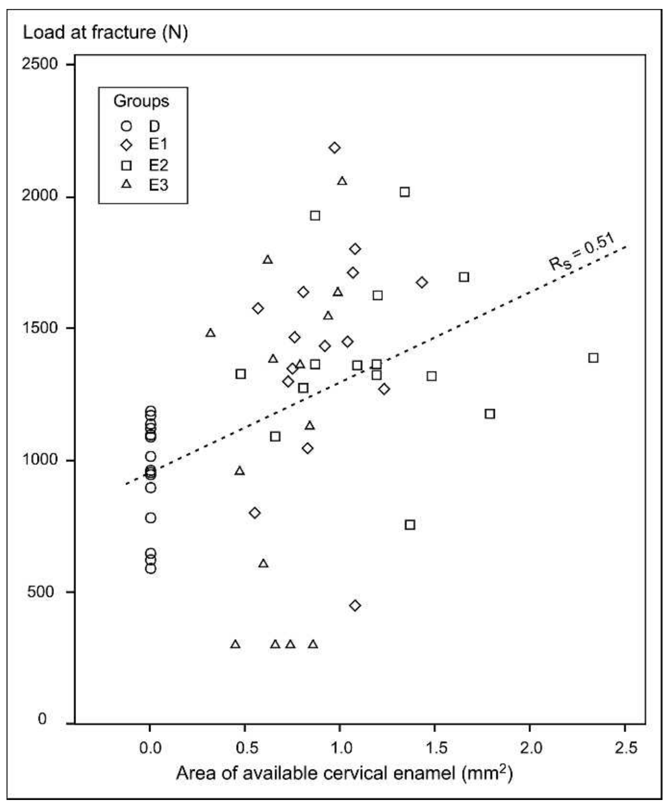

Figure 5. *Scatter plot of area of available cervical enamel and load at fracture in the dentin and enamel groups.* $R_S{}^2$ = *squared Spearman rank correlation coefficient.*

Table 2: *Mode of Fracture in the Proximal Box After Loading*[a]

Group	Restoration Failure Mode		No. Cervical Tear-Out of Tooth Substance, %
	No. Adhesive, %	No. Cohesive, %	
D	12 (80)	3 (20)	1 (7)
E1	3 (20)	12 (80)	7 (47)
E2	8 (53)	7 (47)	8 (53)
E3	8 (53)	7 (47)	5 (33)

[a] *N=15 in each group. Numbers in parentheses are percentages relative to the total number of teeth in each group.*

Table 3: *Extension of the Leakage at the Interface Between the Tooth Substance and Restoration at the Cervical Margin of the Preparation*[a]

Group	No. Extending into Enamel, %	No. Extending into Dentin, %
D	Not applicable	3 (20)
E1	4 (27)	0 (0)
E2	4 (27)	0 (0)
E3	5 (33)	5 (33)

[a] *The teeth with leakage were distributed into two categories, according to if the leakage was observed in enamel only or in dentin. N = 15 in each group. Numbers in parentheses are percentages relative to the total number of teeth in each group.*

Table 3 shows the observed leakage between the tooth substance and restoration at the cervical margin of the preparation.

DISCUSSION

In this *in vitro* study, the fracture strength of the marginal ridge, the fracture mode and the leakage at the cervical margin of posterior composite class II restorations were tested in relation to the location of the cervical margin and the area of the available cervical enamel. The cervical part of a class II restoration is of special interest because this is the most technically challenging part of the cavity in a clinical situation; visual inspection, moisture control, insertion, and light curing of the restorative material are all challenging at this part of the preparation.

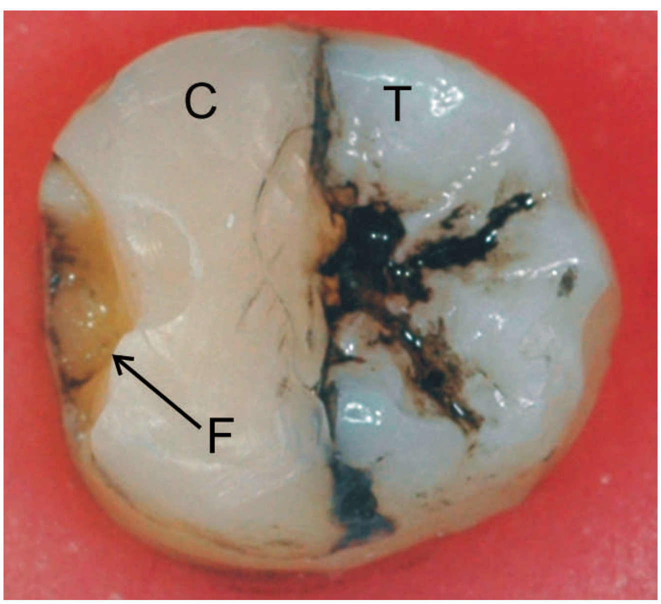

Figure 6. *Fracture of the marginal ridge of a class II composite restoration (C) in a posterior molar (group E3)* in vitro*, after artificial aging and mechanical loading, until fracture. The restoration has a remaining cuspal coverage, and there is a cohesive fracture in the proximal box. The dark staining originates from the tracer material used for testing leakage (T = tooth substance, F = fracture).*

The available enamel at the cervical margin depends on anatomical variations and the location of the cervical margin of the preparation. The anatomy of the teeth makes standardization of the preparations difficult. In this study, standardized preparations were obtained by using a flat-ended conical diamond bur with rounded edges, as has been used in other studies.[30] Four standardized preparation designs were used to reflect common clinical situations, with a special focus on the cervical margin in the proximal area of class II restorations.

The preparations in group E2 were initially prepared as group E1 (4 mm) and then reduced to 3 mm from the occlusal portion. This was done instead of reducing the gingival depth of the preparation because we wanted to keep the enamel thickness as similar as possible compared with group E2.

The preparations in this study were not beveled at the margins because this could complicate the standardization of the preparation design and the measurement of the enamel area. Some authors question the clinical benefit of beveling because of the risk for overhang and underfilled margins.[31]

Others recommend beveling to obtain an optimal marginal seal.[32,33]

Artificial aging of restorations by subjecting them to thermocycling and cyclic preloads is an established method used in laboratory studies to observe factors like marginal quality, microleakage, fracture strength, and wear.[34-37] An accelerated aging procedure in a wet environment will apply thermal and mechanical stresses to the tooth-restoration complex in a way that mimics the clinical situation, although only in a vertical direction.

The use of carbon particles (Indian ink) as a tracer material allows for evaluation and visualization of the microleakage at the cervical tooth/restoration interface.[38]

The fracture strength in the dentin group (group D) was significantly lower than in groups E1 and E2, indicating that composite class II restorations that extend below the CEJ have lower fracture strength at the marginal ridge than those with a cervical margin above the CEJ. Nevertheless, other confounding variables need to be discussed. The height from the marginal ridge to the cervical margin increases when a class II preparation is extended below the CEJ. In the present study, this distance was 6 mm. Studies have shown that the effectiveness of light curing and the degree of conversion decrease with increasing cavity depths.[39,40] However, this effect may not be critical on the marginal quality and leakage, and in fact some authors even report reduced microleakage at a lower degree of conversion.[41]

The preparations in groups E1 and E2 were designed with two different heights (3 and 4 mm, respectively) to address the effect of restoration height on the fracture strength. The present finding that there was no difference between the two groups indicates that height does not have an important influence on strength, at least when enamel is present.

The fracture strength of the restorations in group E3, being similar to that of group D, suggests that reduction of the cusps and cuspal coverage do not enhance the fracture strength. This is in accordance with results from the few available clinical studies.[42,43]

The importance of the area of available enamel at the cervical margin is demonstrated by the positive correlation between the area of available enamel and fracture strength, although this correlation was poor.

Reduced visual access and difficulties in keeping the cervical area free of moisture are other, perhaps more important factors leading to an impaired adaptation between the tooth substance and the restorative material at the cervical level. In this *in vitro* study, we were not able to study this factor.

The traditional notion that presence of cervical enamel is decisive for marginal quality may be challenged by developments in dental adhesion in recent decades. Adhesion to dentin has been emphasized more, and "dentin-friendly" self-etching adhesives have been introduced. Still, simplified adhesive systems do not achieve the same bond strength to enamel as the etch-and-rinse systems,[44,45] and their simplification so far appears to induce loss of effectiveness.[15] The results in this study indicate that the available cervical enamel is important for fracture resistance and fracture mode when using an etch-and-rinse adhesive system. The effect of other adhesive systems needs to be further investigated.

The bond strength achieved with the presence of cervical enamel may resist the shearing forces generated through the restoration by occlusal stress better than when cervical enamel is not present, and this is probably the most important reason for better fracture resistance in this study.

The sound, unprepared molars (controls) had a fracture strength not significantly different from the teeth in groups E1 and E2. These results suggest that a class II composite restoration of the present design, with the cervical margin located in enamel, does not weaken the marginal ridge of a molar.

The fracture mode varied considerably between the dentin group of restorations and the enamel groups (as a pooled group) in the present study. The results indicate that when the restoration is extended below the CEJ, the fractures are of a more adhesive nature than when cervical enamel is present. However, the fractures tended to tear out cervical tooth substance when enamel is present at the cervical margin.

Fracture testing complicates the subsequent detection of leakage. Within the limitations of the leakage detection method used in this study, it seems likely that extensive restorations are more susceptible to leakage. Polymerization shrinkage of a larger volume of composite material entails a greater tendency to form voids between the material and the tooth substance. This may be one explanatory factor to these results, even though a layering technique was used in the present study.

Because the preloading process with cyclic loads was performed directly in dye, we cannot know if the dye penetration is caused by contraction stress from polymerization or stress induced from mechanical loading.

CONCLUSIONS

The fracture strength of the marginal ridge in composite class II restorations that extend below the CEJ (without available cervical enamel) is significantly lower than when the restoration's margin is located coronally to the CEJ (with available cervical enamel). The area of available cervical enamel in the preparation has a positive influence on the fracture strength. Class II restorations that extend below the CEJ have a predominance of adhesive fractures, while those with available cervical enamel have a predominance of cohesive fractures.

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